# Action of a Three Phase Induction Motor under Various Forms of Pressure Waves

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1905

# THE ACTION OF A THREE PHASE INDUCTION MOTOR ~~AND~~ under VARIOUS FORMS of PRESSURE WAVE.

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A THESIS

PRESENTED to the TRUSTEES and FACULTY

of the

ARMOUR INSTITUTE of TECHNOLOGY

FOR THE DEGREE OF

BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING

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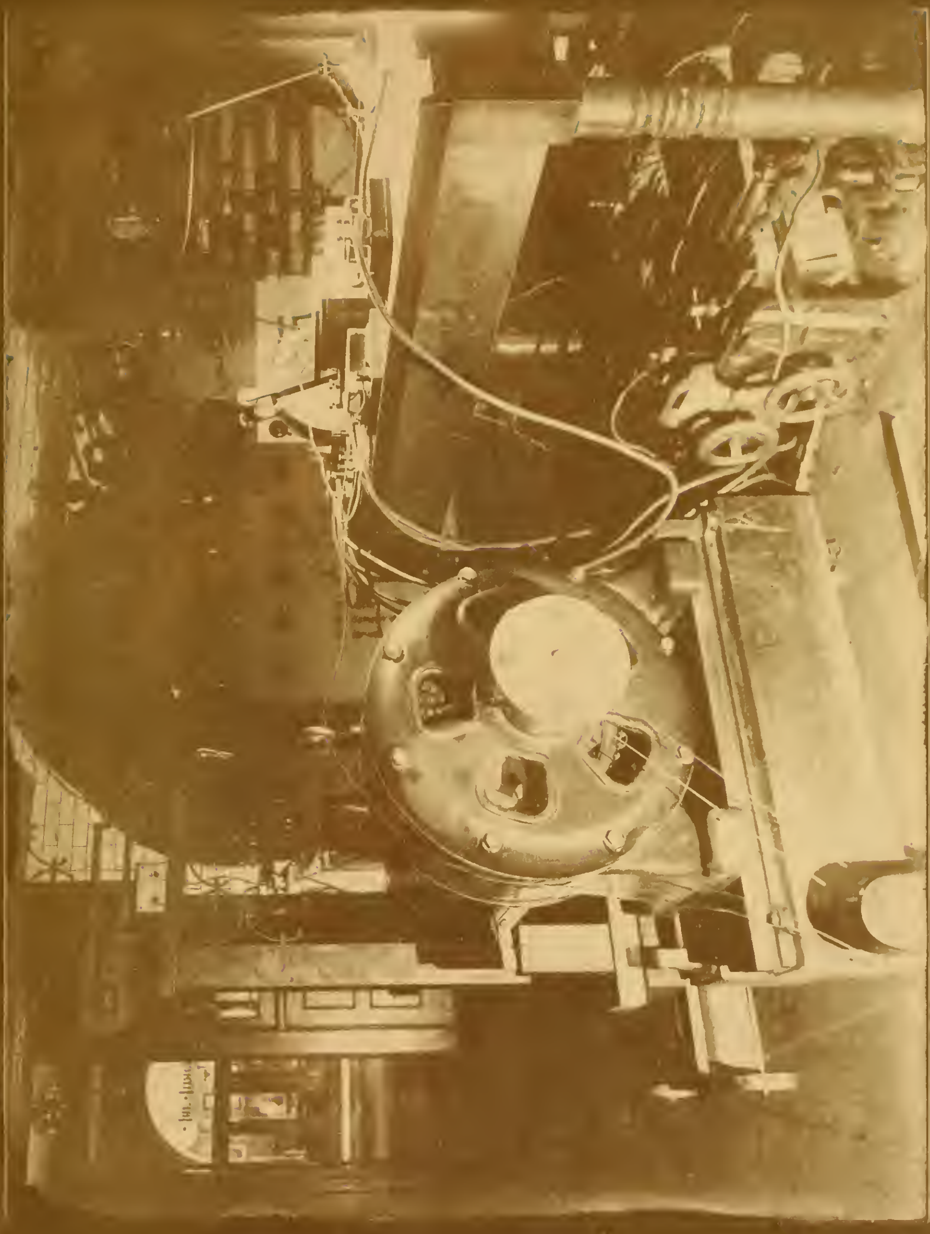


# THE ACTION OF A THREE PHASE INDUCTION MOTOR WITH VARIOUS FORMS OF PRESSURE WAVE.

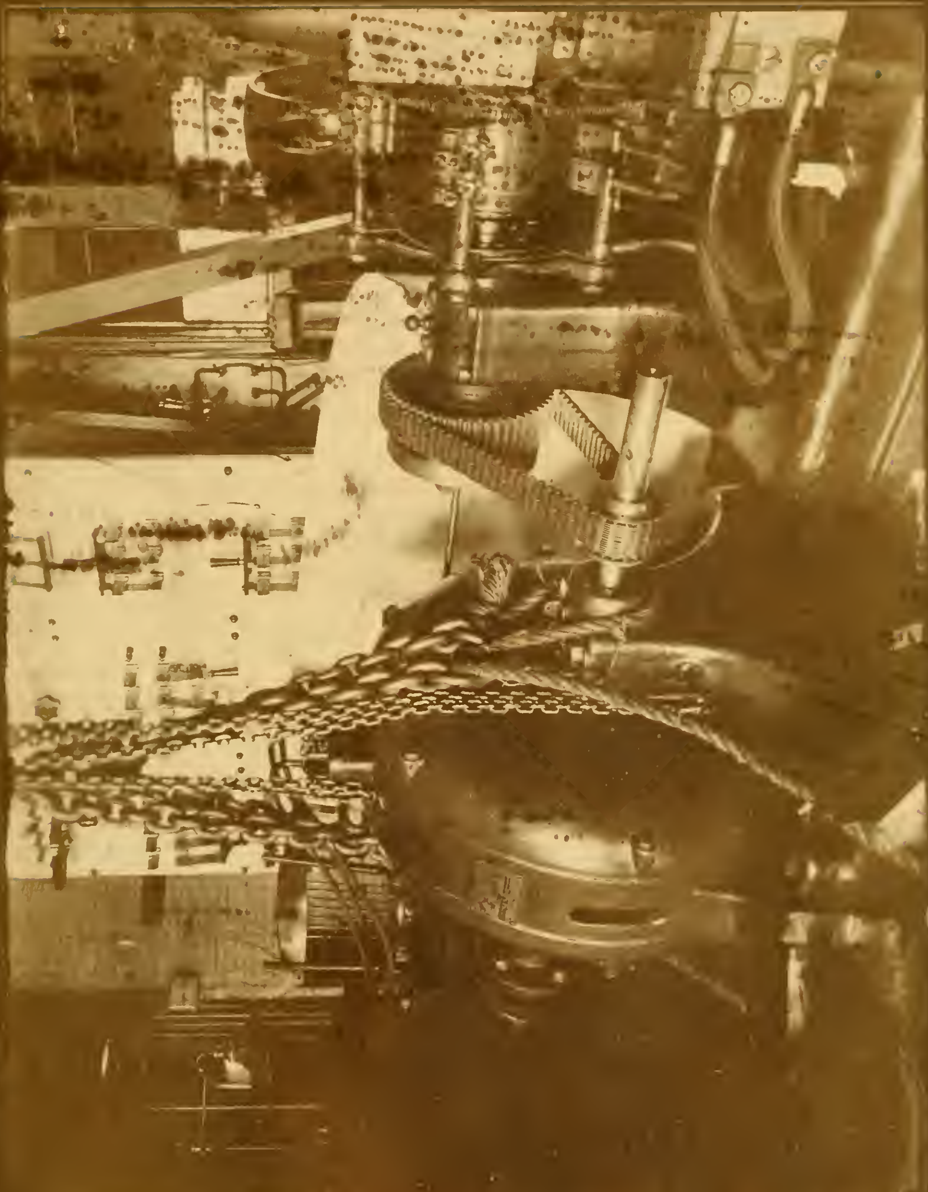
## I N T R O D U C T I O N .

A general study of the effect of wave form upon induction motor performance is not attempted in this discussion, as such an investigation would be impossible with the time and material ordinarily available in a technical course. The object of this paper is to give the results of a few careful tests on a given motor supplied with three phase current by various forms of pressure wave.

The problems met in securing these results were such as to make logical a division of the thesis into two parts:

1st. Securing the wave forms.

2nd. Running the tests.



## PART I.

## PRODUCTION OF WAVE FORMS.

The principal methods of production of distorted wave forms which suggest themselves are these:

1. "Injecting" capacity, inductance or resistance into the external circuit at various points of the wave.

2. Setting up fluctuations in the generator field at similar points.

3. Combination of a fundamental with one or more waves of harmonic frequencies.

The first of these has been used---(See Lond.Elec. 5-15-96), in tests on the iron loss of transformers where small single phase currents were required, but in case of three phase currents of the magnitudes required for starting a squirrel cage motor make the scheme scarcely practicable.

The second method is limited in three phase work by the fact that to retain symmetry of the waves, only certain points may be indentedand also because any fluctuations of field which were of sufficient magnitude to effect the wave were found to heat the magnets excessively due to abnormal iron losses in the solid cores of the only machines available.

The third scheme was the one used and in the application of it in seeming obvious manners some rather unlooked for difficulties were encountered.

The fundamental wave was secured from a "Wood" 2-3 phase rotary, 30 K.W., 85 V., 500 R.P.M.. A third harmonic was secured by running at 1500 R.P.M. A general electric type A.T.B., 15 K.W., 85 V., 6 pole, 60 cycles, 6 phase generator. The two were accurately lined and coupled by a Renold silent chain set purchased from the Link Belt Eng. Co., Chicago, and giving a 3-1 reduction. The large gear was mounted on

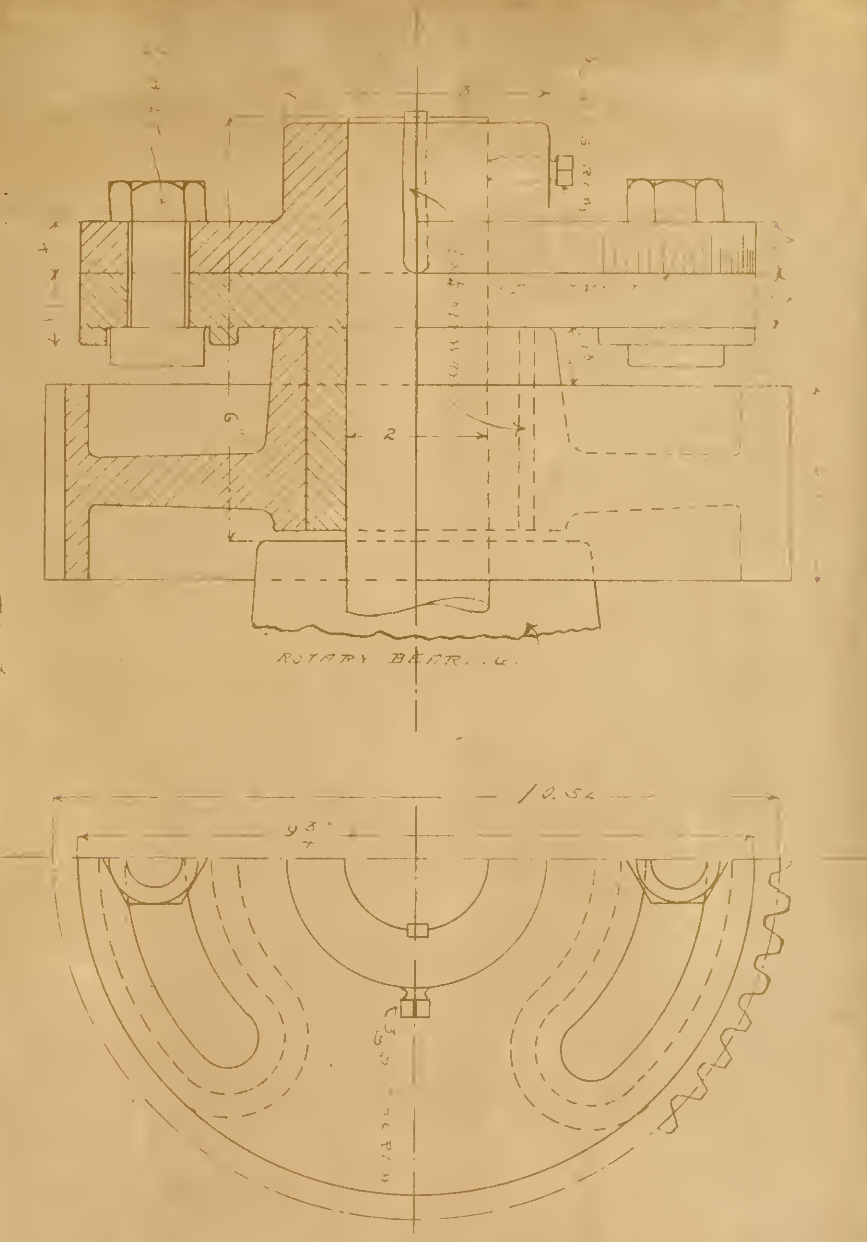



Fig. 1

FIG. 1.

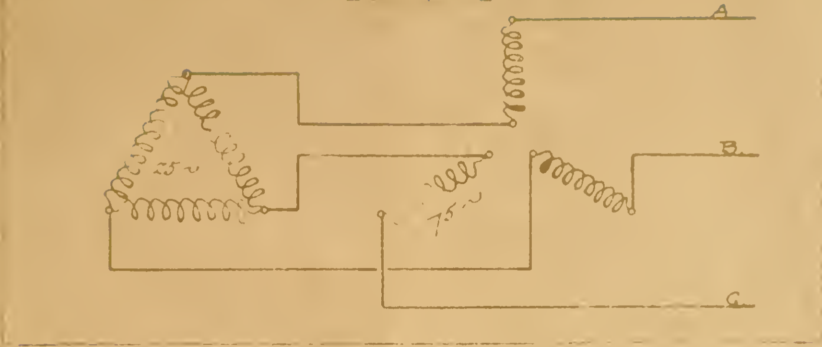



FIG 2.

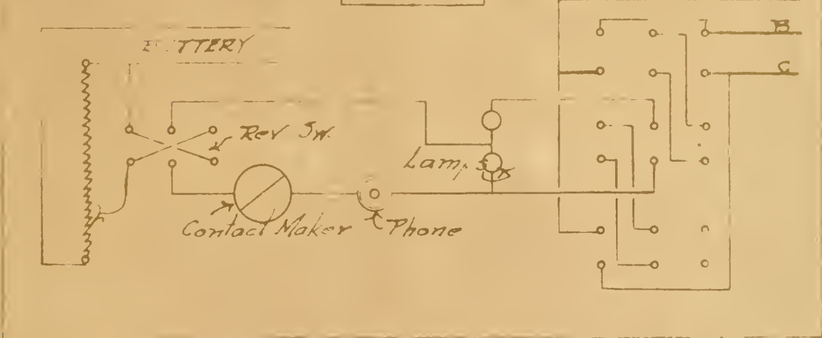
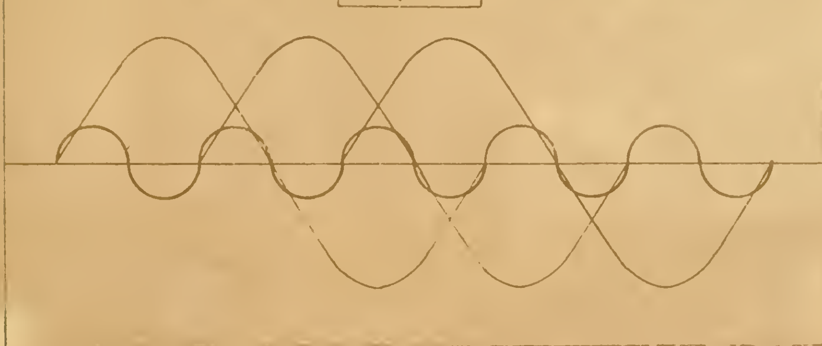



FIG 4.



a special flange made in the Institute Shops and designed to give a possible angular displacement of 360 electrical degrees, relatively to the rotary shaft. Fig. 1 shows this flange in detail. So far as the quietness of running of the set even up to 2,000 revolutions it left nothing to be desired.

The curves were traced by means of a contact maker with a movable brush, coupled to the rotary shaft by a flexible joint. The pressure through it was balanced through a telephone against the drop over a portion of a carbon "potential rheostat" balance being indicated by the point of minimum sound and the pressure read on Weston, D. C. 0-15, 0-150, Voltmeter, No.4392, which was checked against Otto Woolf potentiometer No. 440 and found accurate within .o volts at all parts of the scale. All curves were plotted direct from the voltmeter and contact maker indications, eliminating the taking of data and showing at once any peculiarity of the curve, allowing it to be gone over slowly.

The problem of electrical connections seemed at first glance simple. The 75 cycle generator was given 3 phase connections and a coil placed in each of the rotary leads (Fig.3). Three dissymmetrical waves were produced. This is explained by the fact that to maintain the same phase relations between each pair of 25 and 75 cycle, or fundamental and harmonic coils, the harmonics should plainly differ in phase by 120 degrees on the fundamental scale, or if the expressions may be used, 120 "fundamental degrees" 120 fundamental degrees corresponds to 120 x 3 equals 360 third harmonic degrees or degrees on the harmonic scale. Consequently the thirds should differ in phase by 360 degrees, making them identical. In Fig. 4, 3 phases of the fundamental and a single third is plotted. This brings out the point clearly, showing that the 3 phases will be affected in the same way

FIG [illegible]

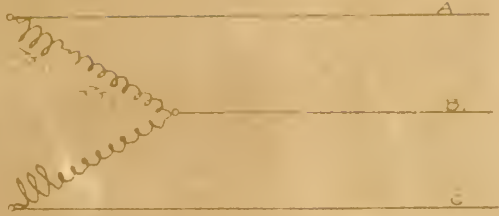



FIG 9

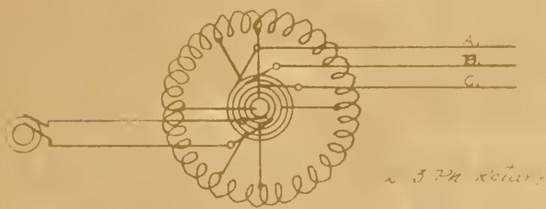
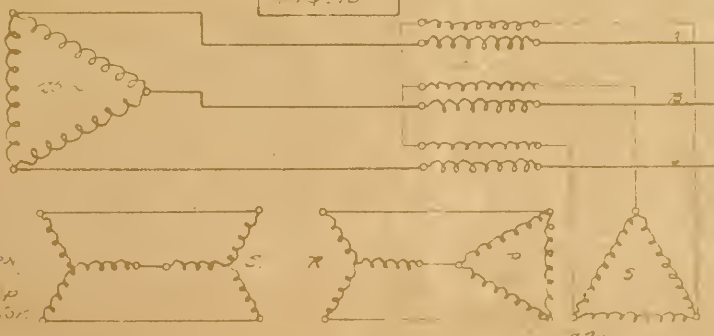



FIG. 10



by a single (or 3 coincident) waves of triple frequency.

To conform to this the low tension sides of 3 phase transformers were put into the rotary leads, and their high tension sides each connected in parallel with that of a fourth transformer excited from a phase of the 75 cycle generator (Fig.5). No distortion of the wave form was produced, the harmonics simply neutralizing each other, a pressure being increased a certain amount going out on one line and cut down the same amount coming back on either of the other two lines. As a method of eliminating this opposition of voltage the harmonic coils were connected inside the delta. As it was impossible to get inside the rotary delta, the rotary pressures were stopped by means of two 3 phase transformers to another delta, the secondary of the final transformer, which could be gotten into.Fig. 6, shows this set of connections.

No distortion of wave was produced. This is due to the fact that the 3 harmonic voltages acting in phase set up cross currents around the delta which exactly counter-balanced their own pressures. This would be analogous at any instant to a scheme such as Fig. 7, where 3 batteries are connected in the sides of a mesh of resistances as indicated. It can at once be seen that the drops over the resistances would leave the P. D. at the corners of the mesh equal to zero.

To eliminate the cross currents the mesh was opened at a point (Fig.8) killing one leg, but still giving a correct 3 phase circuit. This gave two similar waves , but the third was distorted more than the other two, due to two of the harmonics acting on it in series.

One of the waves was used to run a second 2- 3 phase rotary single phase (Fig.9) and waves traced from the 3 phase terminals. They were dissimilar and it began to look as is three similar waves, 120 degrees apart and containing a third could not exist in an interconnected circuit, the thirds

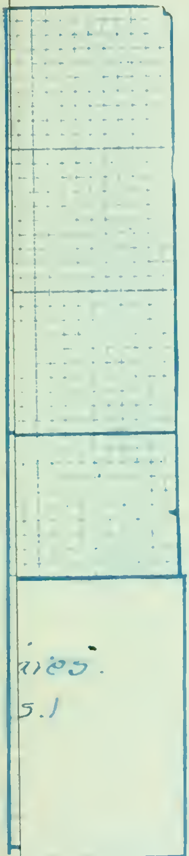
either neutralizing each other in a star, or neutralizing themselves, by a cross current in a mesh.

If three waves of a fifth harmonic frequency be combined with three fundamentals 120 degrees apart, as before, to produce three similar waves, they must differ in phase by 120 fundamentals---120 x 5 equal 600, the equivalent of 120, harmonic degrees. Consequently the objections to the introduction of a third would not hold for a fifth.

It is unfortunate that the time available would not permit a thorough investigation of this interesting point. That the effects of the harmonic are neutralized has been shown clearly above and the means by which it is accomplished seem clear. Indeed in the mesh the actual cross current was measured, and tests with a telephone across the corners of the delta with the full cross current flowing gave only a slight hum, probably due to some unbalanc in the impedances of the sides. With the delta open and the cross current thus eliminated waves showing the effect of the third were secured from a circuit which with the delta closed, gave under the same conditions. These similar sine waves.

The matter seems of considerable theoretical interest. Since a coil generating a wave which is the sum of a fundamental and a third may for purposes of discussion be replaced by two coils in series, one generating the fundamental and the other the third, it seems but a short step to suppose that if a wave comprising a third be generated in any delta connected piece of 3 phase apparatus, a rotary for instance, a cross current will be set up, with a corresponding loss of efficiency. A star connection would be subject to the same loss of power, due to opposition of voltages.

This condition is not likely to exist in 3 phase generating apparatus, for it may be shown (Steinmetz "Phenomona", p.389) that due to the slots per pole of a 3 phaser forming a multiple of 3 the third harmonic is not likely to be prominent due to any distortion of flux, the principal cause of such higher harmonics. Steinmetz further shows, however, (page 392) harmonics set up by fluctuations of reactance such as by hysteresis tend strongly to accentuate

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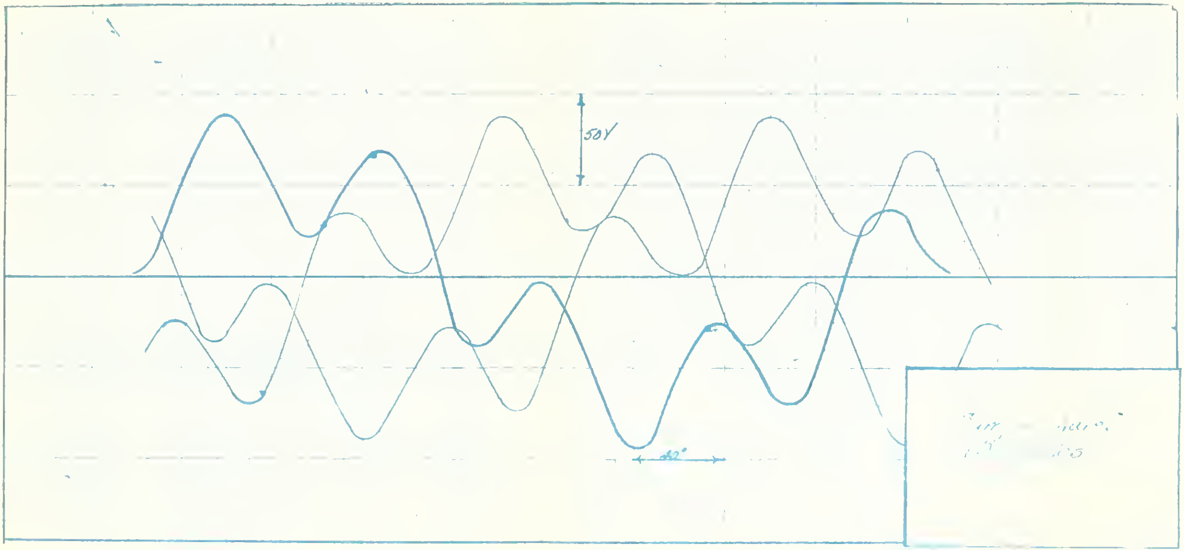


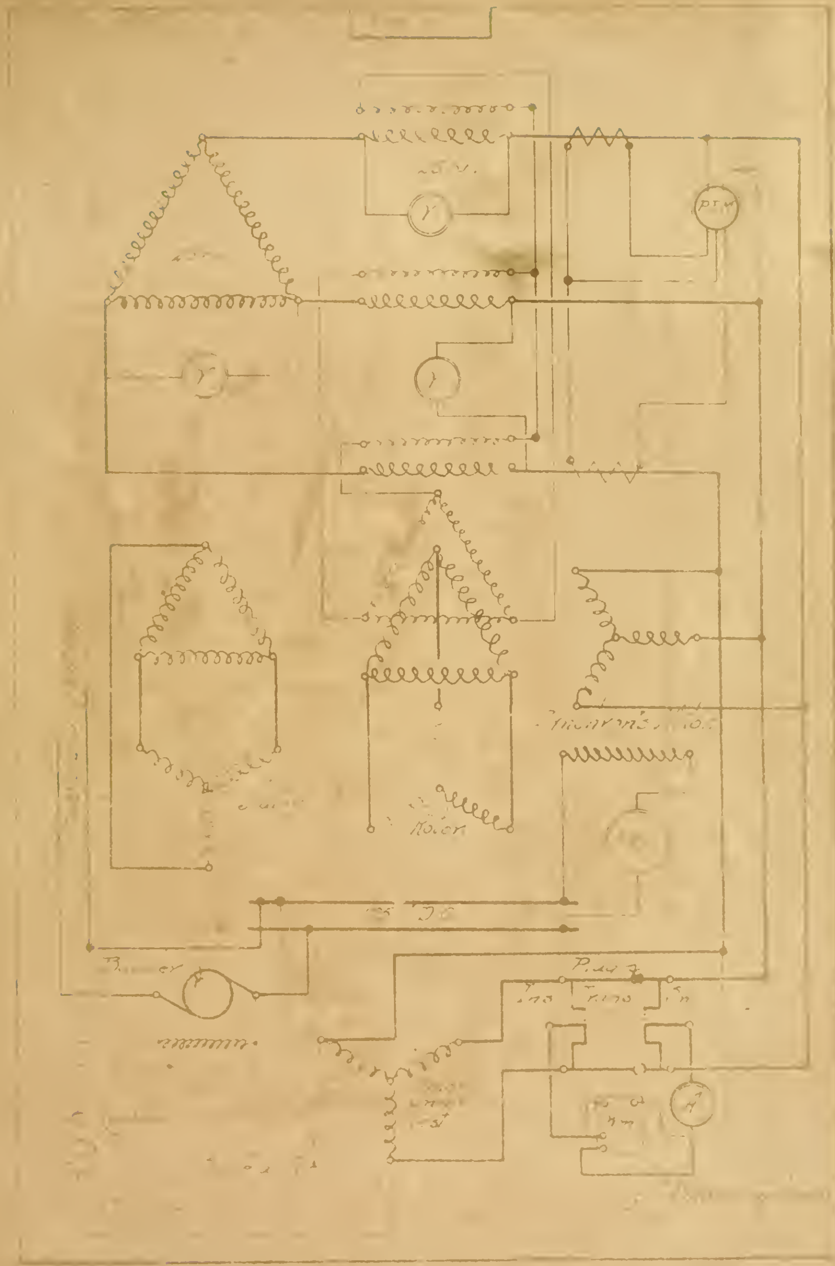
50V

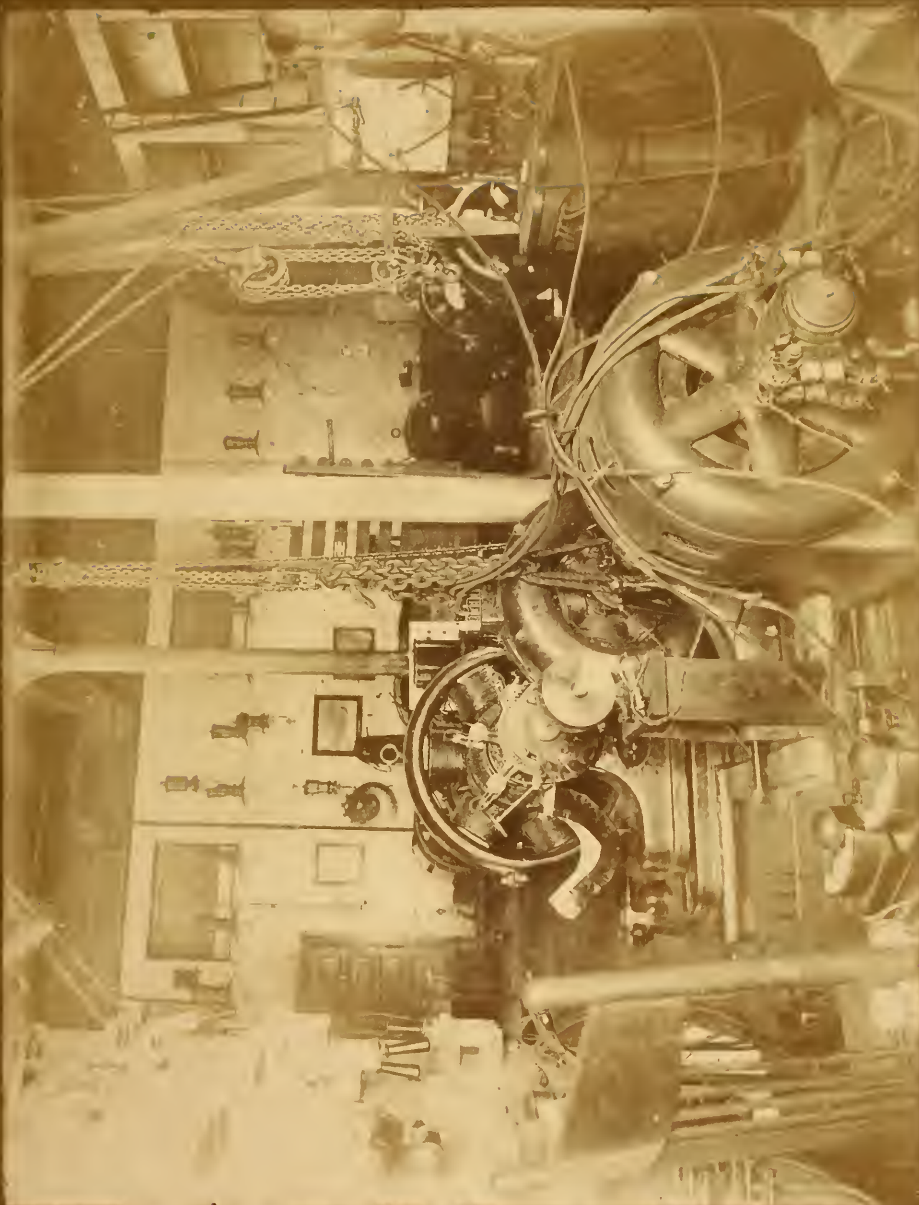
the third harmonic. It is possible that some of the losses in 3 phase transforming apparatus may be due to the above mentioned losses of power and it is possible that ~~the~~ to this may be attributed a share of the "load losses" (Behrend p.27) of induction motors. ¶ Six poles was the maximum of the three phase machines available with a maximum normal frequency of 60 cycles. Even if a 5 to 1 ratio of gears had been available to connect such a machine to the 500 revolution rotary furnishing the fundamental it would have been scarcely advisable to have run the 60 cycle machine at 2500 revolutions--- more than twice its normal speed. A general electric induction motor class 4-10-750 form M (open rotor type) was available and it was coupled direct to the 75 cycle generator driven from the rotary shaft and run backwards at 1500 revolutions, its fields being excited from the 75 cycle current, giving 125 cycles at the rotor terminals. The motor was of but 10 H. P., but as the pressure required was low and a relatively high one could be produced in it, it was arranged to step down the pressure, thus decreasing the current necessary in the rotor to balance the line current. This was accomplished by a 3 phase and 3 single phase transformers as shown by Fig. 10. This gave the wave forms shown in curve II.

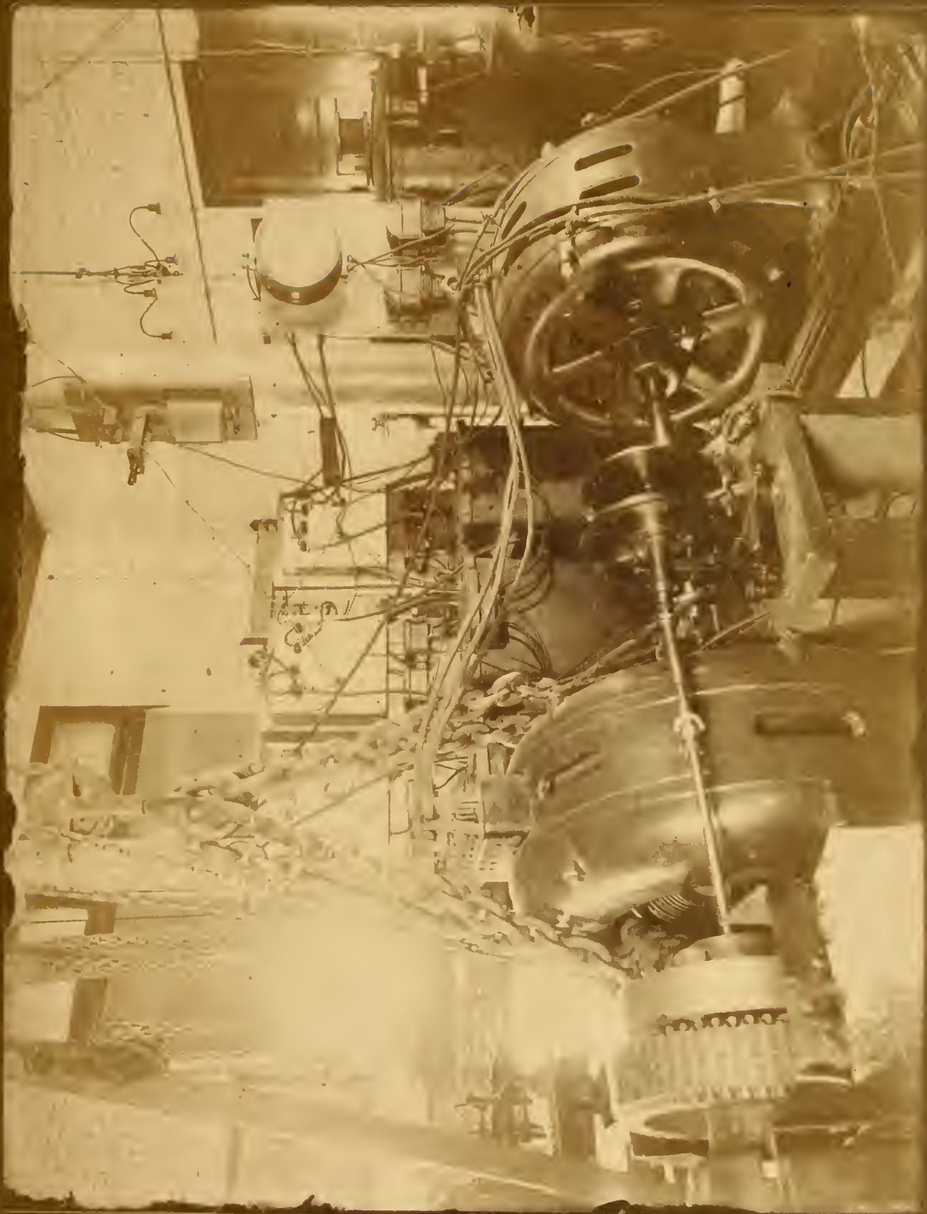
A practical objection to this scheme of series transformers arose from the fact that their inductances ~~exten~~ exerted a depressing influence upon the 125 cycle peaks of the curve as shown by curves 3 and 4, showing the resultant of 65 V fundamental and 12 V harmonic with and without load. Little effect was noticed on the fundamental curve (Curves 5 and 6).

To counteract this effect a synchronous motor and a power factor meter were put on the line as shown in Fig. 11, giving the complete and final scheme. The load and excitation of the synchronous motor were used to adjust the power factor, and curves 8 and 9 were made. A change in the wave form may still be noted, although the ratio of fundamental to harmonic has been unchanged.

Any reactance in the external circuit would affect the fundamental and the harmonic voltages in the ratio of their frequencies. Hence if one must be raised to keep the







total voltage constant as a load comes on, if the other is raised proportionally in the ratio of their frequencies the greater effect of the external reactance on the harmonic should be overcome, and the wave form unchanged. For instance, if the ratio of fundamental to harmonic voltage be as 75 to 15, and the frequencies as 25 to 125, one volt rise of fundamental pressure would require $\frac{125}{25} \times \frac{15}{75} \times 1$ volt equal 1 volt rise in harmonic pressure. This was tried and while with high external reactance (curve 10) it does not work very well, with a fair power factor the curve under load may be made to practically coincide with the no load curve (see surves 8 & 11).

## P A R T II.

## T H E M O T O R T E S T S.

The load curves of an induction motor cover most of the practical demands for information as to its performance. In addition to these the starting and accelerating characteristics, useful for some classes of work can best be determined from a series of speed curves, showing the relation of torque, current, power factor, etc. to speed or to slip.

The motor used was No. 31694 2-3 phase induction motor, General electric type 1 form K.I. (squirrel cage) Some of the principal dimensions of the machine are as follows:

Style I, Q 4-10-750.
Capacity,, 10 P.
Number of poles, - 4,
Cycle speed 25/
R.P.M. 750,
Voltage (3 phase)-80

STATOR.

Circuits per phase 1,
Cond. in series per phase (3 phase) 144,
Size of conductors- 2- No.2 B.W.G.
Cond. per slot 6,
# Slots 72,
Depth 1 1/4",
Width .335
Outside diam. punchings 21".
Inside diam. punchings, 15.7"
Air gap "- .35",
Length of punching 5".

ROTOR.

Winding, Squirrel cage,
#Slots, 47,
Size conductors .5" x .35",
Size slot 1 5/8" deep, 9/16" Bottom 1/10" slit,
Outside diam. punching- 15",
Inside diam. punching 11",
Area short cirx. ring, .94 sq".
Length punching 5"

The following load curves show results of nine tests on as many wave forms:

Current Readings: The current input of the motor was read on Thomson 0-200 ammeter No.24080. Previous to the test it was checked against electrodynomometer No.96 as follows:

| Amperes. | Readings. | Amperes. | Readings. |
|---|---|---|---|
| 22.8 | 22 | 48.6 | 50 |
| 32.8 | 33 | 59.6 | 60 |
| 39.5 | 40 | 62.0 | 62.2 |

For each load the meter was transferred by a special instrument switch to each of two phases and the average taken as the true current indication.

Power Readings: The kilowatt input of the motor was measured by the sum of the readings of Weston 0-100 amp. wattmeter No. 1778, when placed in each of two phases by the instrument transferring switch, the free pressure connection remaining on the third phase. Previous to the tests the meter was checked at a constant d.c. voltage of 100 as follows:

| True K.W. | Reading. | True K.W. | Reading. |
|---|---|---|---|
| 1 | 1.04 | 7 | 7.00 |
| 2 | 2.04 | 8 | 8.04 |
| 3 | 3.04 | 9 | 9.00 |
| 4 | 4.04 | 10 | 10.00 |
| 5 | 5.05 | 11 | 10.97 |
| 6 | 6.06 | | |

The power output was measured by a 13" prony brake of the band type operating on a steel pulley, water cooled. Readings were taken on a Fairbanks 0-525 lb. platform scale at a brake radius of 1.041 feet

Arrangements were made so that proper balance of the brake scales would light an incandecsent lamp in front of the meter, insuring that readings be taken at correct balance.

Voltages: The motor voltage was kept constant at 80 by Weston 0-75-150 voltmeter No. 753. The fundamental portion of this pressure was regulated by Thomson 0-130 voltmeter No.6832 and the harmonic portion by Weston 0-15-25 voltmeter No. 3484.

Speed: All speed readings during the load runs were made with a totation counter and stop-watch. The generator cycle speed was regulated by No.5217 Schaffer & Budenberg tachometer of the belt type. During the, speed runs as mentioned later, Weston tachometer generator No. 13 was belted to the motor shaft and the speed calculated from the indications of No.4401, Weston 0-3 voltmeter. The operation of these magnets speed indicators is too well known to require explanation.

Slip Measurement: The scheme of measuring the small slips incident to the load curves was as follows: A card was

mounted on the motor shaft at right angles thereto, bearing ~~from~~ spots , corresponding to the four poles of the generator, arranged in a circle and illuminated by a hand feed arc lamp fed by same circuit as the motor. If the rotor was revolving at synchionism the spots would advance exactly one position in the half cycle corresponding to a period of comparative darkness of the lamp, and hence would appear stationary. But if the speed is less than synchionism each bright point of the lamp will find the spot a little farther back than before, of the position it would seem to occupy at synchionism. This results in a seeming ~~speed~~ slow backward rotation of the spot at a speed equal to the slip.

It is of interest to note that when a flat wave was used the spots seemed to spread over quite a large surface, due to the long period of brightness, and that when a 2 or 3 peaked wave was used the spots appeared in twos or threes, due to periods of comparative darkness between peaks. This effect became so troublesome that the lamp was wired onto the same portion of the wave by running its leads back to the machine generating the fundamental.

Slip measurements were made by timing the speed (R.P.M.) of these spots with a stop watch.

Tests: The load tests included readings of current, pressure, power and slip as various outputs, from which were calculated the torque, efficiency, power factor and apparent efficiency as shown by the following data and curves.

The power factor of the total current was maintained at unity by Westinghouse power factor meter No.8960.

The speed curves: Considerable trouble was experienced before finding a good method of obtaining the torque, slip curves. It was impossible to merely load the motor until the slip reached the required amount, as the current at full voltage would not only have been excessive even for short application, but the power factor of the total ~~xxxxxx~~ current could not have been maintained at the point necessary to preserve the wave form. (See part I.)

It was attempted to run the generators at low voltage, but it was found impossible in this case to keep the regulating synchionous motor on the line, and enough transformers were not available, either to step up the pressure to it, or to step it down to the induction motor.

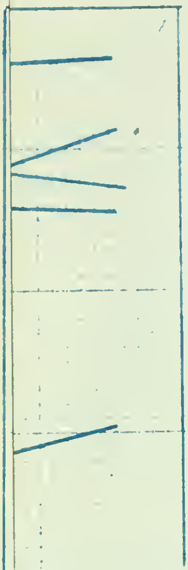
The next scheme tried was a lowering of motor voltage by resistance in the form of lamp racks. While this gave the required pressure it was found impossible to keep it constant for any speed, the loss of voltage in it varying with the motor current, which in time varied with the slip so rapidly that when a given slip was reached the voltage would not ~~xxxx~~ be correct and any attempt to change it would result in wide variations of speed.

The method as finally determined was this: The brake was removed and sufficient voltage was applied to the motor to keep it running, if started by hand, to overcome static friction. Readings of speed and current were then made and the torque and current calculated for full voltage at this slip, since the torque at any speed varies as the voltage squared and the current as the voltage. Readings for any other speed were taken by adjusting the voltage until the desired speed was reached and repeating the readings. The friction torque was assumed constant and if numerical results were desired instead of merely comparative ones, could have readily been determined. It was sufficient, however, to take this torque as unity, simplifying calculations. Care was taken that the speed was constant at the time of reading eliminating the torque of acceleration.

Current readings were made with Thomson 0-100 ammeter No. 70184 and voltages with Weston 0-15-25 voltmeter No.3484.

One curve only was obtained with the flat wave. As the thesis was at this point some weeks overdue we had to quit.


Wave No. 1
Wave No. 2
Wave No. 3



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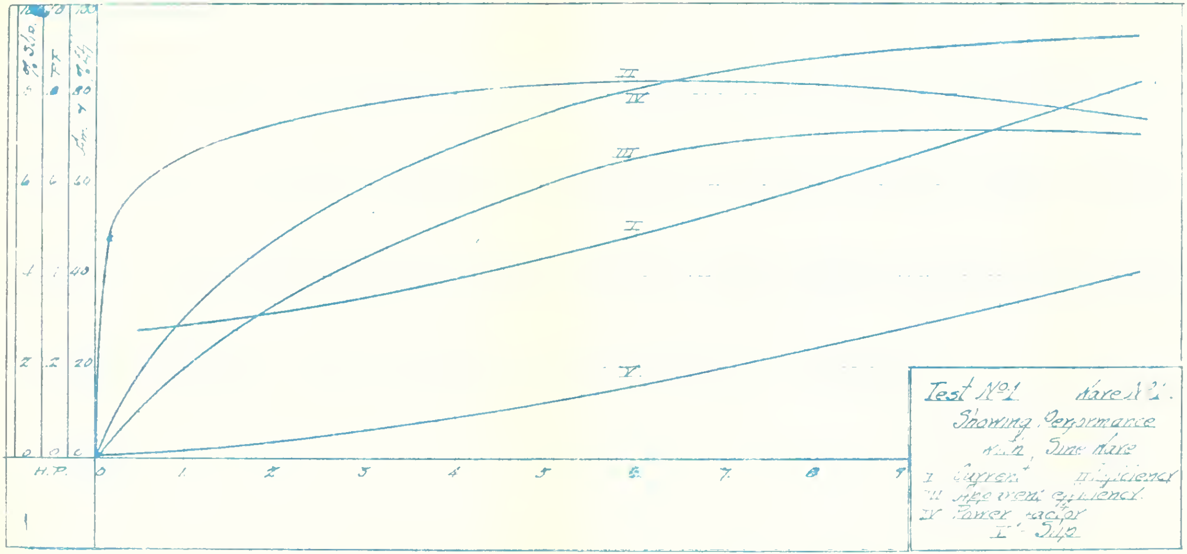
Test N° 1
Wave N° 2.
Showing Performance
with Sine Wave
I Current
II Efficiency
III Apparent efficiency
IV Power factor
V Slip
H.P.
0
1
2
3
4
5
6
7
8
9
I
II
III
IV
V

TEST I. Wave No.1, 80 V. 25 Cycles, Brake radius, 1.041.

| Amp. | K.W. | Lbs. on Brake Net. | Torque | R.P.M. | H.P. Output | Eff. | App. Eff. | PF. | Slip % |
|---|---|---|---|---|---|---|---|---|---|
| 27.1 | .63 | 3.3 | 3.44 | 750 | .511 | 60.5 | .10 | .168 | .216 |
| 29.75 | 1.6 | 10.5 | 10.93 | 740 | 1.54 | 71.9 | .28 | .389 | .67 |
| 36.4 | 3.02 | 20.5 | 21.35 | 735 | 2.98 | 73.8 | .443 | .6 | .85 |
| 41.5 | 4.11 | 30.5 | 31.78 | 735 | 4.44 | 80.5 | 57.5 | .715 | 1.13 |
| 49 | 5.49 | 40.5 | 42.15 | 735 | 5.9 | 80.2 | 64.9 | .809 | 1.68 |
| 55.6 | 6.56 | 50.5 | 52.5 | 728 | 7.27 | 82.6 | 70.5 | .853 | 2.52 |
| 64.9 | 8.02 | 60.5 | 63. | 731 | 8.76 | 81.5 | 72.8 | .894 | 2.85 |
| 72.7 | 9.11 | 70.5 | 73.45 | 730 | 10.2 | 75.5 | 68.3 | .905 | 3.64 |
| 82.5 | 10.65 | 80.5 | 83.7 | 725 | 11.58 | 75.5 | 70.2 | .93 | .0 |

TEST 2. Wave 2. 25 Cycles, etc .

| Amp. | K.W. Input | Lbs. on Brake net. | net Torque | RPM | H.P. Output | Eff. % | App. Eff. | PF | Slip |
|---|---|---|---|---|---|---|---|---|---|
| 37.50 | .84 | 1.5 | 1.56 | 755 | .214 | 19.95 | 3.23 | .162 | .2 |
| 39 | 1.95 | 10 | 1.04 | 754 | 1.47 | 56.4 | 20.3 | .361 | .5 |
| 41.7 | 3.0 | 2.0 | 20.82 | 750 | 2.97 | 74.0 | 38.5 | .52 | .98 |
| 46.2 | 4.28 | 30 | 31.23 | 742 | 4.41 | 77.0 | 51.4 | .669 | 1.45 |
| 53.1 | 5.48 | 40 | 41.64 | 745 | 5.9 | 80.5 | 60.0 | .745 | 1.85 |
| 59.7 | 6.81 | 50 | 52.0 | 735 | 7.27 | 79.6 | 65.7 | .825 | 2.52 |
| 65.2 | 7.97 | 60 | 62.40 | 732 | 8.69 | 81.5 | 72.0 | .884 | 3.2 |
| 75.7 | 9.15 | 70 | 72.8 | 725 | 10.07 | 82.0 | 71.4 | .872 | 3.7[illegible] |
| 87.2 | 10.82 | 80 | 83.2 | 720 | 11.41 | 78.5 | 70.1 | .894 | 4.77 |
| 97.2 | 12.05 | 90 | 93.6 | 715 | 12.74 | 78.8 | 70.4 | .894 | 5.33 |

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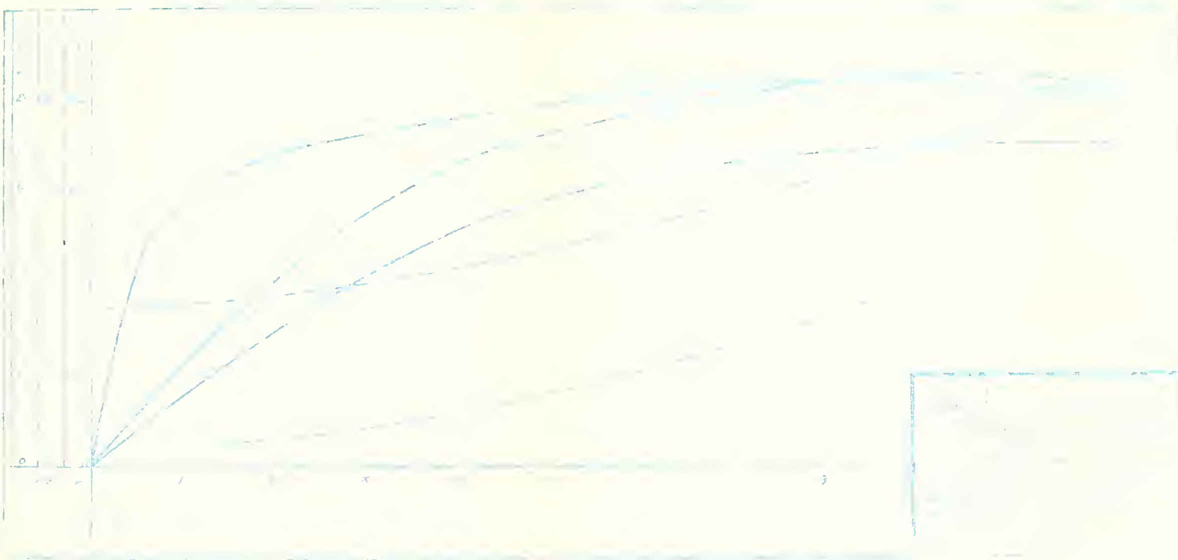

TEST NO.3 Wave 3---

| Amp. | KW | Lbs.on Brake net. | Torque. | RPM | H.P. output | Eff. % | App. Eff. | PF | Slip |
|---|---|---|---|---|---|---|---|---|---|
| 33 | 1.09 | 1.25 | 1.3 | 775 | 1.91 | | | .239 | .28 |
| 35.6 | 1.79 | 10.25 | 10.67 | 765 | 1.63 | 68.0 | 24.07 | .354 | .504 |
| 39.5 | 3.09 | 20.25 | 21.1 | 754 | 3.03 | 73.0 | 41.2 | .565 | .83 |
| 44.5 | 4.32 | 30.25 | 31.5 | 750 | 4.49 | 77.5 | 54.3 | .701 | 1.43 |
| 52.3 | 5.43 | 40.25 | 41.9 | 745 | 5.94 | 81.5 | 61.0 | .749 | 2.75 |
| 58.0 | 6.47 | 50.25 | 52.3 | 740 | 7.36 | 84.8 | 68.3 | .805 | 3.5 |
| 67.5 | 7.88 | 60.25 | 62.7 | 740 | 8.82 | 83.5 | 70.3 | .842 | 3.16 |
| 76.6 | 9.19 | 70.25 | 73.1 | 730 | 10.18 | 82.8 | 71.6 | .854 | 3.74 |
| 87 | 10.52 | 80.25 | 83.5 | 720 | 11.45 | 81 | 70.8 | .873 | 6.3 |
| 96.8 | 12.12 | 90.25 | 93.9 | 720 | 12.89 | 79.1 | 71.5 | .903 | 7.15 |

TEST NO. 4   Wave 4   25 Cycles, 80 Volts, Brake Rad. 1.041

| Amp. | KW | Lbs.on Brake. | Torque | RPM | HP Output | Eff% | App. Eff. | PF | Slip % |
|---|---|---|---|---|---|---|---|---|---|
| 54 | 1.45 | 5.25 | 5.46 | 745 | .774 | 39.8 | 7.7 | .194 | .67 |
| 52 | 2.4 | 13.75 | 14.32 | 743 | 2.01 | 62.9 | 21 | .334 | .94 |
| 58 | 3.9 | 23.75 | 24.72 | 740 | 3.48 | 66.6 | 32.5 | .468 | 1.34 |
| 69 | 5.08 | 33.75 | 35.1 | 735 | 4.91 | 72.0 | 38.4 | .532 | 2.0 |
| 72 | 7.0 | 43.75 | 45.5 | 730 | 6.33 | 67.5 | 47.5 | .705 | 2.68 |
| 77 | 8.1 | 53.75 | 55.9 | 725 | 7.72 | 70.9 | 53.9 | .76 | 3.35 |
| 84 | 9.4 | 63.75 | 66.3 | 720 | 9.08 | 72.0 | 58.5 | .81 | 4.04 |

5

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Wave

fficiency

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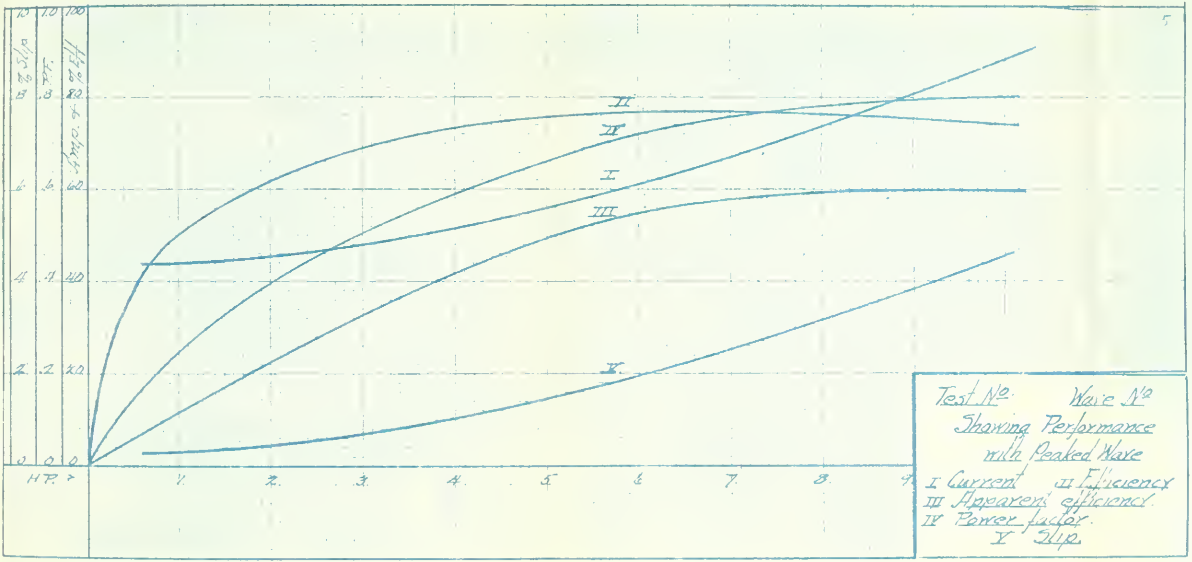

% Slip
P.F.
Amp. + % Eff.
10 1.0 100
8 .8 80
6 .6 60
4 .4 40
2 .2 20
0 0 0
H.P.
1. 2. 3. 4. 5. 6 7. 8. 9.
I
II
III
IV
V.
Test No. Wave No.
Showing Performance with Peaked Wave
I Current II Efficiency
III Apparent efficiency
IV Power factor
V Slip

TEST NO. 5, Wave 5, 25 cycles, etc.---

| Amp. | KW | Lbs. on Brake Net. | Torque | RPM | H.P. Output | Eff. % | App. Eff. | PF | [illegible] |
|---|---|---|---|---|---|---|---|---|---|
| 40 | 1.19 | 4.05x.2x | 4.21 | 755 | .605 | 37.9 | 8.15 | .215 | .28 |
| 49 | 2.15 | 11.25 | 11.72 | 750 | 1.67 | 56.3 | 14.5 | .317 | .50 |
| 52 | 3.56 | 21.25 | 22.15 | 750 | 3.16 | 66.2 | 32.8 | .495 | .65 |
| 54.3 | 4.56 | 31.25 | 32.53 | 740 | 4.58 | 74.9 | 45.5 | .607 | 1.61 |
| 59 | 5.85 | 41.25 | 42.95 | 734 | 6.07 | 77.5 | 56.1 | .724 | 2.0 |
| 68.5 | 7.13 | 51.25 | 53.3 | 725 | 7.36 | 77.2 | 58.0 | .753 | 2.67 |
| 81 | 8.61 | 61.25 | 63.75 | 720 | 8.72 | 75.6 | 57.9 | .767 | [illegible].43 |
| 90.5 | 10.17 | 71.25 | 74.1 | 716 | 10.12 | 74.1 | 60.4 | .815 | 4.67 |

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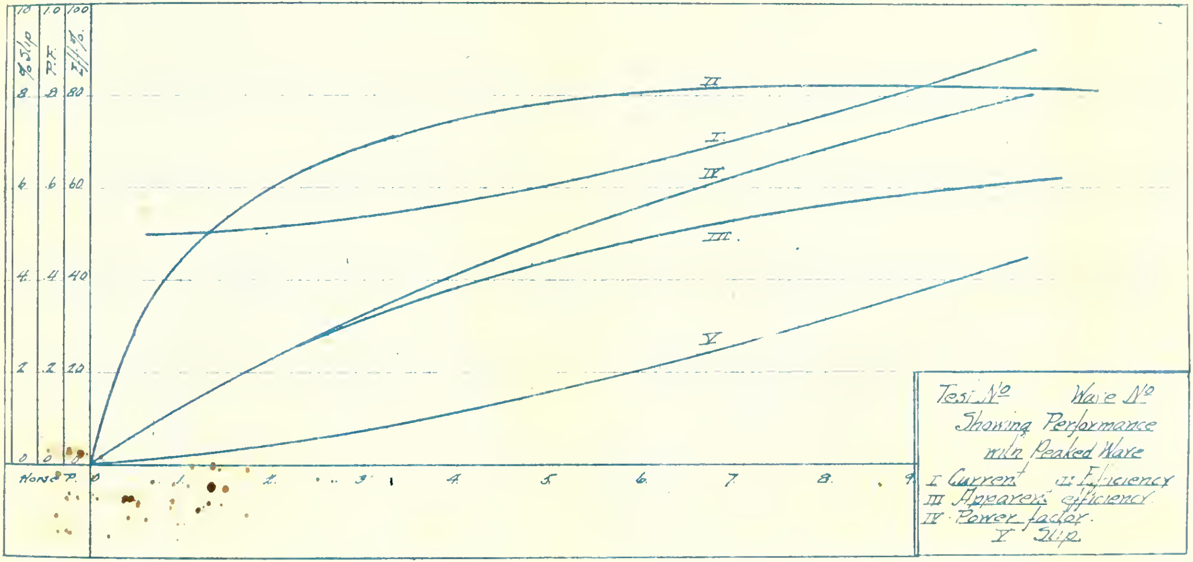
mance

Wave

fficiency

ciency.

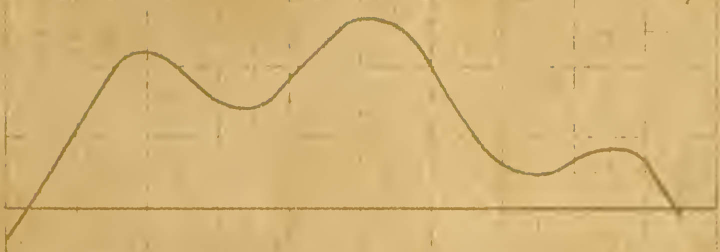


10
1.0
100
% Slip
P.F.
Eff. %
8 .8 80
6 .6 60
4 .4 40
2 .2 20
0 0 0
Horse P.
0 .1 .2 .3 .4 .5 .6 .7 .8 .9
II
I
IV
III
V
Test No Wave No
Showing Performance
with Peaked Wave
I Current II Efficiency
III Apparent efficiency
IV Power factor
V Slip

TEST NO. 6 Wave No. 6, 25 cycles, 80 V, etc.

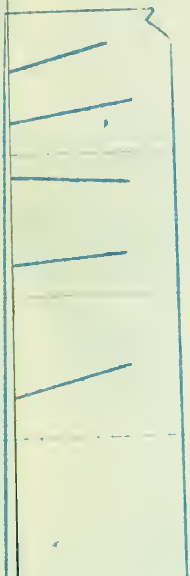
| Amp. | KW | Lbs. on Brake Net. | Torque, | RPM | H.P. output | Eff. % | App. Eff. | PF | Slip % |
|---|---|---|---|---|---|---|---|---|---|
| 50.8 | 1.4 | 4.5 | 4.68 | 747 | .665 | 35.5 | 7.07 | .198 | .28 |
| 50 | 2.3 | 13 | 13.53 | 740 | 1.91 | 61.7 | 20.5 | .332 | .615 |
| 57 | 2.65 | 23 | 23.95 | 739 | 3.36 | 70.1 | 24 | .342 | 1.2 |
| 59 | 4.8 | 33 | 34.35 | 735 | 4.8 | 74.6 | 43.9 | .588 | 1.65 |
| 64.5 | 5.14 | 43 | 44.75 | 729 | 6.2 | 80 | 46.0 | .575 | 2.11 |
| 73.8 | 6.53 | 53 | 55.1 | 725 | 7.6 | 86.6 | 55.3 | .639 | 2.45 |
| 82 | 8.16 | 63 | 65.5 | 720 | 8.97 | 82.2 | 59 | .718 | 3.87 |
| 90 | 10.15 | 73 | 76.0 | 715 | 10.32 | 75.8 | 61.7 | .813 | 4.6 |

Wave No 7.



Wave No 8.

Wave No 9.



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Efficiency
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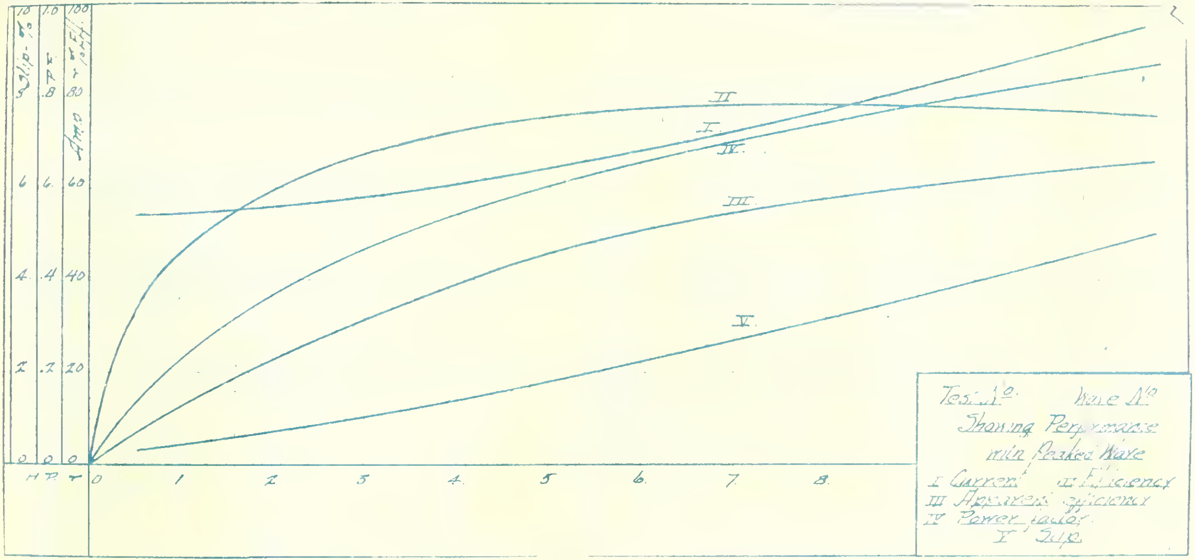

Test No.
Wave No.
Showing Performance
with Peaked Wave
I Current
II Efficiency
III Apparent Efficiency
IV Power Factor
V Slip
H.P.
0 1 2 3 4 5 6 7 8

TEST NO. 7. Wave No. 7, 25 cycles, etc.

| Amp. | KW | Lbs. on brake, Net. | Torque | RPM | H.P. output | Eff. % | App. Eff. | P.F. | Slip % |
|---|---|---|---|---|---|---|---|---|---|
| 53 | 1.2 | 3.45 | 3.59 | 750 | .512 | 31.9 | 5.24 | .164 | .25 |
| 56 | 2.32 | 11.25 | 11.72 | 743 | 1.65 | 53.2 | 15.9 | .300 | .64 |
| 62 | 3.4 | 21.25 | 22.15 | 739 | 3.1 | 68 | 27.0 | .397 | .953 |
| 59 | 4.65 | 31.25 | 32.53 | 735 | 4.55 | 73 | 41.7 | .571 | 1.67 |
| 66 | 5.90 | 41.25 | 42.95 | 726 | 5.92 | 75 | 48.5 | .647 | 2.36 |
| 72 | 7.17 | 51.25 | 53.3 | 725 | 7.35 | 76.5 | 55.1 | .722 | 3.08 |
| 82 | 8.65 | 61.25 | 63.75 | 724 | 8.78 | 75.8 | 57.7 | .762 | 3.44 |
| 87 | 9.91 | 71.25 | 74.1 | 720 | 10.15 | 76.4 | 63 | .825 | 4.15 |
| 96 | 11.32 | 81.25 | 84.5 | 718 | 11.56 | 75.9 | 64.9 | .852 | 5.05 |

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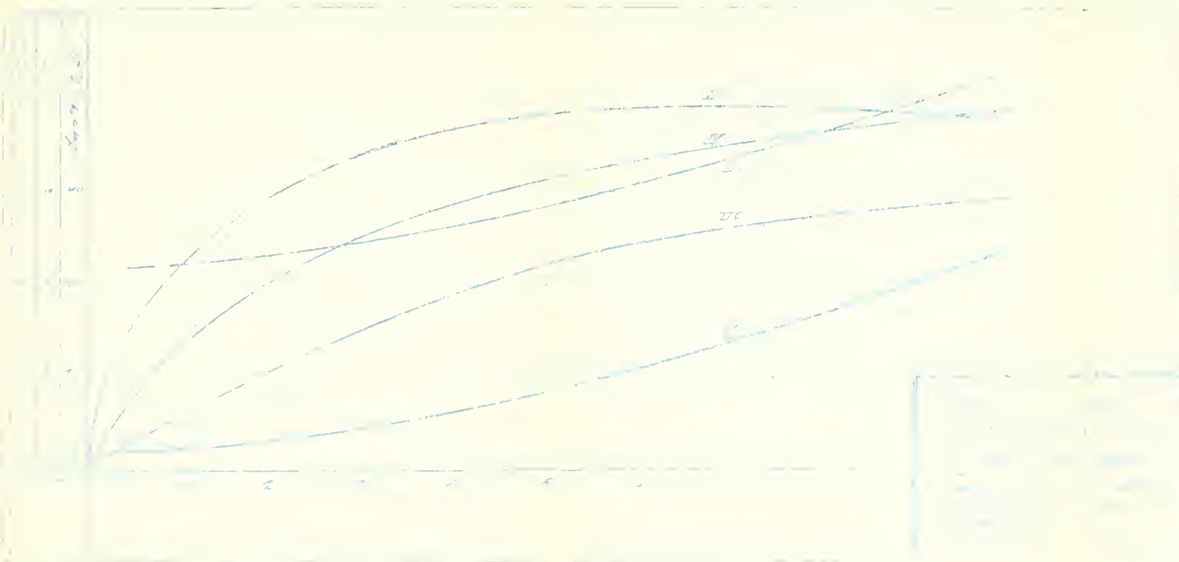
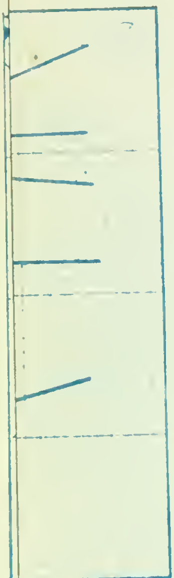
[illegible]ener
[illegible]



TEST NO. 8, Wave No. 8, 25 cycles, 80 V--

| Amp. | KW | Lbs. on Brake, Net. | Torque | RPM | H.P. output | Eff. % | App. Eff. | PF | Slip, % |
|---|---|---|---|---|---|---|---|---|---|
| 43 | 1.02 | 2.95 | 3.07 | 748 | .436 | 32 | 5.48 | .173 | .26 |
| 43.5 | 2.11 | 11.25 | 11.72 | 745 | 1.66 | 48.7 | 17.1 | .35 | .60 |
| 54 | 3.5 | 21.25 | 22.15 | 750 | 3.16 | 67.4 | 31.6 | .469 | 1.1[illegible] |
| 6[illegible].2 | 4.65 | 31.25 | 32.55 | 740 | 4.76 | 76.3 | 42.5 | .558 | 1.72 |
| 64.8 | 5.94 | 41.25 | 42.95 | 732 | 5.97 | 75.1 | 49.7 | .662 | 2.3[illegible] |
| 74.5 | 7.25 | 51.25 | 53.3 | 725 | 7.35 | 75.6 | 53.2 | .703 | 2.92 |
| 80.4 | 8.49 | 61.25 | 63.75 | 722 | 8.75 | 7[illegible].9 | 58.5 | .762 | 3.[illegible] |
| 91.8 | 9.82 | 71.25 | 74.1 | 710 | 10 | 7[illegible].1 | 58.8 | .77 | 4.7 |



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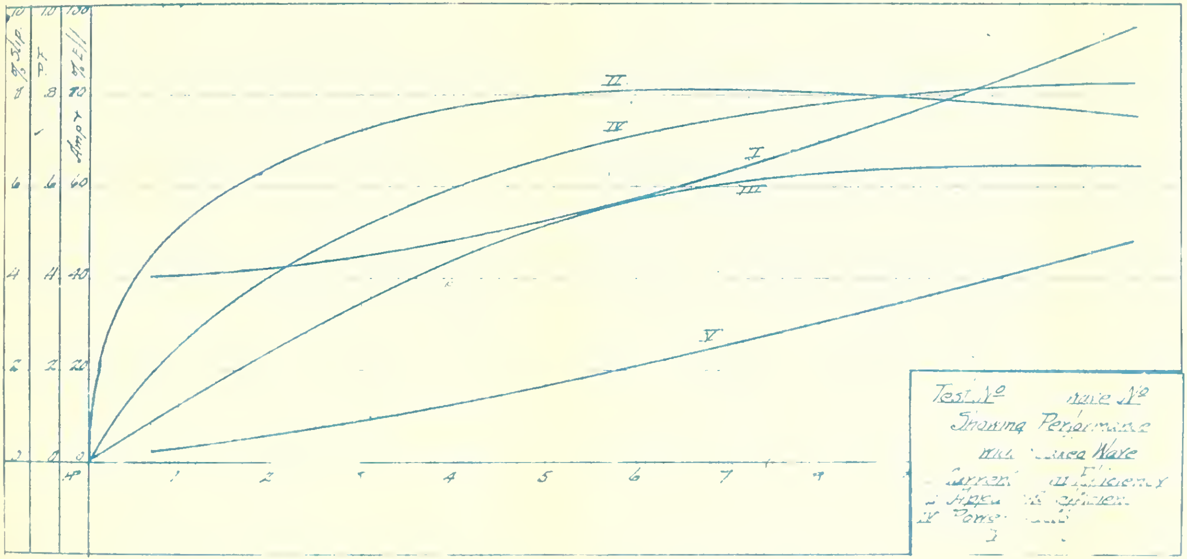

% Slip
P.F.
Amp + % Eff
10
1.0
100
8
.8
80
6
.6
60
4
.4
40
2
.2
20
0
0
0
1
2
4
5
6
7
II
IV
I
III
V
Test No
Showing Performance
Wave

TEST NO. 9, Wave No. 9, 25 cycles, et.

| Amp. | KW | Lbs. on Brake Net. | Torque | RPM | H.P. output | Eff.% | App. Eff. | P.F. | Slip % |
|---|---|---|---|---|---|---|---|---|---|
| 40.5 | 1.1 | 2.6 | 2.5 | 750 | .67 | 45 | 8.8 | .197 | .22 |
| 42 | 2.02 | 10.93 | 10.5 | 748 | 1.62 | 59.9 | 20.6 | .347 | .57 |
| 44.9 | 3.13 | 21.35 | 20.5 | 745 | 3.05 | 72.1 | 36.3 | .503 | 1.01 |
| 50.6 | 4.64 | 31.78 | 30.5 | 745 | 4.5 | 72.3 | 47.9 | .662 | 1.71 |
| 58.2 | 5.67 | 42.15 | 40.5 | 740 | 5.93 | 79.4 | 55.9 | .705 | 2.11 |
| 65.7 | 6.92 | 52.5 | 50.5 | 732 | 7.32 | 79.9 | 61.0 | .763 | 2.8 |
| 74.6 | 8.23 | 63.0 | 60.5 | 732 | 8.76 | 80.5 | 64.0 | .795 | 3.27 |
| 84.1 | 9.61 | 73.45 | 70.5 | 725 | 10.12 | 78.5 | 64.8 | .826 | 4.0 |
| 95.1 | 11.0 | 83.7 | 80.5 | 720 | 11.48 | 77.8 | 64.9 | .835 | 5.0 |

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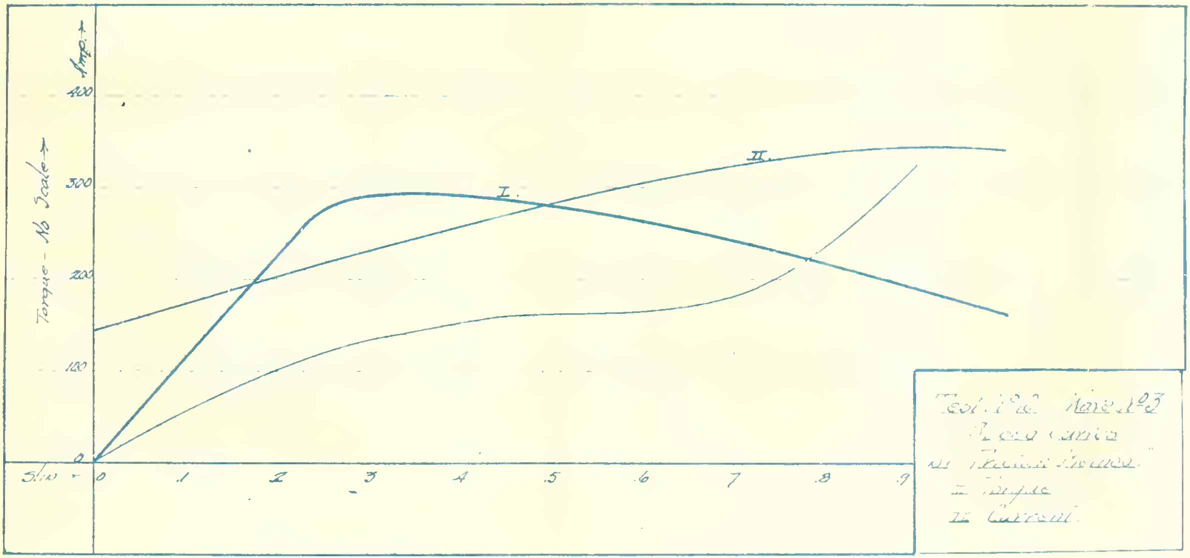

Amp. →
400
300
200
100
0
Torque - No Scale →
I.
II.
Slip →
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
No 3
II Current

TEST NO. 10. Wave No. 3, Speed Curves.

| Speed | Slip. | Voltage, | Torque, | Current, | Current 80 V |
|---|---|---|---|---|---|
| 0 | 1.0 | 5.8 | | | |
| 72.2 | .905 | 6 | 178 | 24.2 | 334 |
| 32.1 | .432 | 6.1 | 172 | 24 | 320 |
| 161 | .785 | 5 | 256 | 26 | 340 |
| 265 | .647 | 5 | 256 | 25 | 400 |
| 3[illegible]1 | .519 | 5.1 | 246 | 24.5 | 393 |
| 481 | .359 | 4.65 | 297 | 24.5 | 485 |
| 561 | .252 | 4.7 | 290 | 28.1 | 484 |
| 625 | .167 | 5.95 | 181 | 28 | 477 |
| | | | | 27 | 364 |